INTERNATIONAL STANDARD

ISO 11520-1

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Agricultural grain driers — Determination of drying performance —

Part 1: General

Séchoirs à grains agricoles — Détermination des performances de séchage —

Partie 1: Généralités

Reference number
ISO 11520-1:1997(E)

Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11520-1 was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 7, *Equipment for harvesting and conservation*.

ISO 11520 consists of the following parts, under the general title *Agricultural grain driers — Determination of drying performance*:

— *Part 1: General*

— *Part 2: Specification of crop quality, moisture content and performance correction method*

Annex A forms an integral part of this part of ISO 11520. Annexes B to E are for information only.

Introduction

It is envisaged that many grain drier tests will be carried out by independent bodies, either to help manufacturers in development work or for specification of performance to potential purchaser/owner or other interested body. While it is possible to conduct a test on the basis that only input and output parameters are recorded, the extra cost of making internal measurements is likely to be small relative to the benefit in a diagnostic sense of the additional data. For this reason the standard includes procedures to make such measurements.

Agricultural grain driers — Determination of drying performance —

Part 1:
General

1 Scope

This part of ISO 11520 describes methods for evaluating the drying performance of continuous flow and batch grain driers. The methods specified are for determining the evaporation rate which the machines concerned are able to achieve under the steady-state conditions prevailing during the tests. Methods for correcting observed performance to other input and standard ambient conditions are described.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 11520. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 11520 are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 520:1977, *Cereals and pulses — Determination of the mass of 1 000 grains.*

ISO 712:1985, *Cereals and cereal products — Determination of moisture content (Routine reference method).*

ISO 3966:1977, *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes.*

ISO 7194:1983, *Measurement of fluid flow in closed conduits — Velocity-area methods of flow measurement in swirling or asymmetrical flow conditions in circular ducts by means of current-meters or Pitot static tubes.*

ISO 7971:1986, *Cereals — Determination of bulk density, called "mass per hectolitre" (Reference method).*

3 Definitions

For the purposes of this part of ISO 11520, the following definitions apply.

3.1 continuous-flow drier: Drier in which the material being dried moves through the machine in a substantially continuous stream and is discharged without being recirculated.

3.2 batch drier: Drier in which the drying chamber is completely emptied between the drying of separate batches of grain.

3.3 ambient air temperature and relative humidity: Mean dry bulb temperature and mean relative humidity of the atmosphere measured as close as possible to the main air intake(s) of the drier, but not affected by the drier;

the mean value of relative humidity over a period is that corresponding to the mean absolute humidity and mean dry bulb temperature of the air over that period.

3.4 standard ambient conditions: Ambient conditions of temperature, pressure and relative humidity to which the results of a drier test shall be corrected.

NOTE — See ISO 11520-2.

3.5 steady state: For a continuous-flow drier, a period during which both the moisture content of discharged grain and the temperature of the exhaust air are stable.

3.6 residence time: For a continuous-flow drier, the mean time taken for grain to travel from the input to the output.

3.7 stabilization period: Period during which a continuous-flow drier is operated so that it approaches steady state.

3.8 test period: Period during which a continuous-flow drier, operating at a single steady state for at least one residence time, or a batch drier, completing a single full cycle of drying and cooling, is monitored to enable its thermodynamic performance to be assessed.

3.9 input moisture content: Mean wet basis moisture content (m.c.w.b.) of the grain entering the drier during the period of time equal to a test period and beginning one residence time prior to the start of the test period.

3.10 output moisture content: Mean wet basis moisture content (m.c.w.b.) of the grain leaving the drier during a test period.

3.11 input: Mean mass flow rate of damp grain at the input moisture content into a continuous-flow drier during a test period.

3.12 output: ⟨continuous-flow drier⟩ Mean mass flow rate of dried grain which is output during a test period.

3.13 output: ⟨batch drier⟩ Mass of the dried batch divided by the sum of the test period and the filling and emptying period.

3.14 volumetric drier holding capacity: ⟨continuous-flow drier⟩ Volume of grain in the drier after a period of stable operation.

3.15 volumetric drier holding capacity: ⟨batch drier⟩ Volume of grain required to fill the drier at the input moisture content.

3.16 drying air temperature: Mean temperature of the air to be used for drying the grain, measured at a number of points as close as practicable to its entry to the grain bed.

3.17 cooling air temperature: Mean temperature of the air to be used for cooling the grain, measured at a number of points as close as practicable to its entry to the grain bed.

3.18 exhaust air temperature: Mean temperature of the air exhausting from the drier.

3.19 discharged grain temperature: Temperature of grain immediately after discharge from the drier.

3.20 evaporation: Total mass of water evaporated during a test period.

3.21 evaporation rate: Mean rate of evaporation measured over the test period for a continuous-flow drier or over the residence time for a batch drier.

3.22 specific total energy consumption: Total energy used per kilogram of water evaporated.

NOTE — Energy used by conveyors and elevators is not included unless they form an integral part of the drier.

3.23 specific thermal energy consumption: Thermal energy used per kilogram of water evaporated.

3.24 indirect heating: Form of heating in which a heat exchanger is used to heat the air for drying.

3.25 direct heating: Form of heating in which a drier uses fuel that is combusted in the air which is passed through the crop.

4 Symbols and abbreviations

Symbol	Quantity	Unit
A	total mass of grain required for test	kg
B	rated output	kg/s
E	evaporation mass	kg
F	fuel consumption	kg/s
G	holding capacity of drier	kg
H	net calorific value of fuel	J/kg
I	electrical current	A
J	specific fuel consumption	kg/kg
M	moisture content of grain, wet basis	%
N	anticipated number of test periods	1
P	power	W
Q	specific heat consumption	J/kg
S	specific energy consumption	J/kg
U	electrical tension	V
V	volumetric capacity of drier	m^3
W	energy consumption	J
X	flow rate of heating media in heat exchanger	kg/s
c	specific heat capacity	J/(kg·K)
d	depth of grain bed	m
f	face area at point of air entry to grain bed	m^2
g	correction factor for air density	1
h	specific enthalpy	J/kg
m	mass of grain	kg
m'	mass flow of grain	kg/s
p	pressure	Pa
q_v	air volume flow rate	m^3/s
q_m	air mass flow rate	kg/s
r	proportion of air recirculation	1
s	standard deviation	
t	duration of test period	s
v	air superficial velocity	m/s
w	mass of water	kg
x	absolute humidity of air	kg/kg

Symbol	Quantity	Unit
Θ	thermodynamic temperature of air	K
ε	relative error	1
θ	Celsius temperature of air	°C
ρ	density	kg/m^3
τ	residence time in drier	s
υ	specific volume of dry air	m^3/kg
ψ	relative humidity of air	1
$\cos\phi$	power-factor	1
η	thermal efficiency of heater	1

Subscripts

a	ambient, atmosphere
b	barometric
c	cooling
d	drying
e	electrical
f	final; at drier exit
g	grain
h	heating media in heat exchanger
i	initial, at drier inlet
n	total
o	observed value
s	corrected value at standard or specified conditions
t	thermal
v	vapour
w	wet bulb
x	exhaust

5 Principle

For continuous-flow drying the basis of the test is to monitor the drier during a relatively short period with steady-state conditions fully established, rather than over a long period with fluctuating conditions. For batch driers the basis is to monitor the drier during a full cycle of operation. This approach allows

— the drier to achieve maximum evaporation for the test conditions;

— the comparison of results between different driers;

— the results to be corrected to specified input and standard ambient conditions.

6 Instrumentation and specifications

6.1 Automatic recording

If an automatic recording system is used, it should be as immune as possible to electrical interference induced in the sensor cables by nearby electrical equipment. Sensor cables should be installed, as far as possible, away from cables carrying large currents.

6.2 Sensors for air properties

6.2.1 Air temperature

The temperature measuring system shall have a maximum error of 1 °C or 1,5 % of the measured value in degrees Celsius, whichever is greater. Radiation shielding shall be used where a sensor is in direct line of sight of surfaces which have temperatures greater than 500 °C.

Sensors shall be capable of maintaining the prescribed accuracy when operating in an airstream which may contain dust and fine particles.

6.2.2 Air humidity

Measuring systems for relative humidity (r.h.) shall have a maximum error of five percentage points of relative humidity. Other sensors shall be sufficiently accurate to enable r.h. to be calculated to within five percentage points.

6.2.3 Static pressure

Sensors shall be constructed in accordance with ISO 3966. A manometer of suitable range, and able to operate in different mode, is required. It shall have a maximum measurement error of 5 % of the measured value.

6.2.4 Barometric pressure

If an aneroid barometer is used, its calibration shall be checked.

6.3 Grain properties

6.3.1 Grain moisture content

The moisture content of samples of grain shall be determined in accordance with ISO 712.

NOTE — If moisture content is determined by the rapid method, although rapid moisture meters are not, in general, very accurate they are normally consistent between samples over short periods and so provide a very good indication of trends in the moisture content of grain being discharged from the drier.

6.3.2 Grain mass

The mass of grain discharged from the drier shall be measured on a device with a maximum error of 1 % of the measured grain mass.

NOTE — The mass of any tare, e.g. trailer, should be as small as feasible. If the mass of grain is determined by subtraction of two masses, this will increase the error in the measurement of grain mass.

6.4 Energy

Energy consumption shall be measured within ± 2 % of the measured value.

6.4.1 Electrical energy

Electricity consumption shall be measured by an integrating measuring instrument or by continuous measurement of voltage, current and power factor.

6.4.2 Fuels

If the fuels is combusted *in situ*, the net calorific value of the fuel shall be

— determined in accordance with an appropriate national standard;

— taken from an appropriate source, e.g. the standard specification of the fuel; or

— the value certified by the supplier.

The method of measurement of the mass of fuel depends on the energy source for the air heater, e.g. liquid petroleum fuel (diesel oil, liquified gas, etc.), gaseous fuel (natural gas, propane, etc.), solid fuel (coal, straw, etc.) or thermal fluid (hot water, steam, etc.). See annex C.

7 Preparation for test

7.1 Specification of the drier

A record shall be made of the drier specification. Annex E gives a checklist to be followed. As many of the points in the checklist as are applicable shall be recorded.

7.2 Preparation of grain

For a continuous-flow drier, the quantity of dry grain required for a test is given by

$$A = 1{,}1\ [G + N\ (1{,}5\ G + Bt)]$$

where G is taken to be the nominal drier holding capacity. This formula provides for 1,5 complete residence times to separate each test period and a safety margin of 10 %.

For a batch drier, the minimum quantity of dry grain required is

$$A = NG$$

If a safety factor is required, the quantity shall be increased to:

$$A = (N + 1)G$$

7.3 Installation of sensors

7.3.1 Sensors for air temperature

Sensors for temperature shall have a maximum error of 1 °C of 1,5 % of the measured value in degrees Celsius.

7.3.1.1 Drying air temperature

Sensors shall be installed in the air stream as close as possible to the point where it enters the grain bed. To detect spatial gradients in air temperature as it enters the grain bed, a minimum of six sensors shall be installed, equally spaced on a two by three grid.

NOTE — Particular care should be taken to install additional sensors at the locations where the highest temperatures are likely, as these values will be important in assessing the reasons for any thermal damage to grain.

7.3.1.2 Cooling air temperature

At least one sensor shall be installed in the air stream as close as possible to the point where it enters the grain bed. However, sensors shall not be installed close to surfaces which will be hot during the test.

7.3.1.3 Temperature of air inlet(s) to heater

Install at least one sensor shielded from sources of radiant heat.

NOTE — This temperature is required to calculate the temperature rise of the air over the heaters.

7.3.1.4 Exhaust air temperature

Sensors shall be installed in the air stream as close as possible to the point where it leaves the grain bed. To detect spatial gradients in air temperatures at the point where air leaves the grain bed and to give overall exhaust air temperature, a minimum of six sensors shall be installed, equally spaced on a two by three grid.

Exhaust air temperatures indicate the progress of drying. For example in a continuous-flow drier, the approach to steady-state can be detected by steady values of exhaust air temperature from the whole drier, and particularly the exhaust air temperature at the end of the drying section. One of the sensors shall be installed at this point.

7.3.1.5 Fitted sensors

To check the placing and calibration of any temperature sensors supplied with the drier for monitoring or controlling temperature, place an additional sensor close to each one.

7.3.2 Sensors for humidity of inlet air (drying and cooling)

For driers not employing any recirculation of exhaust air, a single sensor shall be located in the air to be heated for the drying section.

7.3.3 Direct method for determining grain temperature

The direct method for determining grain temperature should preferably be used. In this method, for the measurement of ingoing and outgoing grain temperatures, sensors shall be installed in the buffer zone or discharge hopper of the drier.

Sensors installed in the grain bed to measure grain temperature shall not be subject to a flow of air, otherwise they will tend to register the air temperature. This is particularly so for a discharge hopper where there may be

— air leakage through the grain, and

— grain in the ventilated beds.

In these cases the sampling method given in 8.2.4.1 should be used.

7.3.4 Sensors for air static pressure

Sensors shall be installed to measure the difference in static pressure across the grain bed(s), and across the fan(s).

8 Grain sampling

8.1 Before the test

This procedure shall be carried out whether or not the grain is to be dampened.

Mentally divide grain bulk into approximate lots of 20 t each.

From each lot, take 40 samples of not less than 50 g each and bulk to provide one 2 kg sample.

For each 2 kg sample, mix by sample divider and remove, by sample reduction, 100 g. Determine the moisture content as specified in ISO 712.

Take a 200 g sample from the remainder of each 2 kg sample, seal each in a fine-mesh bag and dry with substantially unheated air prior to storage in a moisture proof container at 10 °C. Determine the mass of

1 000 grains in accordance with ISO 520 and the moisture content in accordance with ISO 712. Germination and purity are analysed as specified in ISTA (International Seed Testing Association) rules.

Bulk and mix the remaining grain from each 2 kg sample and reduce the whole by sample dividing to a 3 kg sample, seal in a netting bag and, if necessary, condition to a suitable moisture content for storage. Determine bulk density by a method in accordance with ISO 7971.

8.2 During the test

8.2.1 Choice of sampling points

If the average condition of outlet grain is required, sampling should be done after the grain has passed any device in the grain handling line which mixes the grain, e.g. a screw conveyor. If grain is discharged in batches from the drier or from a hopper, care should be taken that the samples taken are representative of the batch, as the properties of the first and last grain in the batch may be significantly different. The position of inlet sampling point, which should be downstream of devices such as grain cleaners, is less critical than that of the output sampling point as the grain conditions are not likely to vary greatly. Samples may be taken from the drier itself to determine the properties of the grain inside the machine.

8.2.2 Quantity per sample

For each sample, at least 50 g of grain shall be taken from an extracted volume of 1 l.

NOTE — Some analyses may be done on each individual sample, e.g. moisture determination, whereas others may be done on samples formed by bulking individual samples over a test period, if information on variations during the test period is not important.

8.2.3 Frequency of sampling for grain moisture content

8.2.3.1 Continuous-flow driers

The frequency of sampling from the outgoing grain stream(s) shall be such that a minimum of 12 samples are obtained, spaced evenly over a test period. The timing and frequency of sampling of the ingoing grain stream shall be such that

— the grain sampled corresponds with that which will leave the drier during the test period, and

— a minimum of 12 samples evenly spaced in time are obtained.

NOTES

1 This may mean that some input samples are taken but later found to be unnecessary.

2 During stabilization periods the sampling rate of outgoing grain can be reduced.

8.2.3.2 Batch driers

At least 12 samples from the batch of grain to be dried shall be taken, spread evenly over the loading period. At least 50 samples from the batch of dried grain shall be taken during emptying, spaced evenly over the unloading period.

8.2.4 Treatment of samples

8.2.4.1 Sampling method for determining grain temperature

Each of the 12 samples for temperature determination shall be tested immediately. Grain shall, within 5 s of sampling, be placed and held in a preconditioned insulated container until a temperature sensor in the container has reached a maximum. The temperature shall then be recorded.

NOTE — A vacuum flask of at least 500 g capacity is a suitable container and can be preconditioned by filling with a sample from the same source which is then discarded.

8.2.4.2 Moisture determination

Samples for moisture determination shall be placed in sealed containers until required for analysis. Because samples may be warm and moist when they are placed in the containers, some condensation may occur on the inside of the container. Care needs to be taken that all such moisture has been reabsorbed before the container is opened for analysis.

NOTE — Polythene (polyethylene) bags which are heat-sealed or polythene bottles with tightly fitting lids have been found suitable.

8.2.4.3 Other analyses

Samples for other analyses shall be bulked for subsequent analysis; as far as possible samples taken at adjacent intervals shall be bulked to accumulate sufficient grain for testing.

NOTE — This is to retain, even in the bulked samples, the time variation which may be important for later assessment of performance.

Care needs to be taken that each bulk is thoroughly mixed before subsequent use.

8.2.4.4 Germination

If samples for germination are taken, they shall be placed in air-permeable material and ventilated with air at a temperature of less than 30 °C until 15 % m.c.w.b. is reached.

8.3 Determination of grain mass

8.3.1 Timing

Where the output grain stream is continuous the flow shall be diverted for weighing during a timed period equal to the test period. The diverted grain shall be that material which left the drier during the test period, so the diversion may need to be delayed at the start and end of the test period depending on the time taken by the grain to be transported from the discharge of the drier to the diversion point. If the drier has an intermittent or cyclically varying discharge, the test period shall start and end at the same point in the discharge cycle.

8.3.2 Loss of material in exhaust airstream

Care shall be taken to ensure that amounts of grain removed in the exhaust airstream are small.

NOTE — If there are no grain leaks, the loss of mass of the grain on drying comprises the water evaporated and any particles lost in the exhaust air. If the grain is reasonably free of dust and small particles, the latter will be negligible unless grains are entrained in the airstream and carried out of the grain chamber.

9 Test procedures

The drier shall be connected to all required services as specified by the manufacturer and shall be in working order. The required proportion of cooling shall be set.

9.1 Continuous-flow drier

9.1.1 Start up

Fill the drier with damp grain.

Switch off any automatic control of discharge rate.

Route the output grain to a discard store.

Set the required drying air temperature using the manufacturer's installed proprietary equipment.

Set the discharge mechanism to give an output rate corresponding to an appropriate reduction of grain moisture.

Start up the drier following any recommended procedures.

Although some alteration of settings may be necessary initially, once suitable settings have been found, they shall be left unchanged for stabilization period and the test period.

9.1.2 Stabilization period

Begin sampling input and output grain. On a time base, plot moisture contents determined by the rapid method.

After one complete residence time, as indicated by the discharge of a mass of grain equal to the capacity of the drier, the onset of steady state shall be judged by

— the stabilization of the moisture content of the output grain determined by the rapid method, and

— the temperature of the exhaust air form the end of the drying section.

The drier shall be at steady state during the test period, therefore sufficient time for good stabilization shall be allowed.

NOTE — Since the progress to steady state is asymptotic it is usually not possible to determine precisely its onset and it often takes longer than the duration of one residence time.

9.1.3 Test period

The test period shall begin at a convenient time, and as soon as possible after steady state is reached.

At a prearranged signal or time, divert the output grain into the facility [e.g. holding bin or trailer(s)] where it is to be accumulated for the test period.

Record the start time of the test period such that any automatically recorded data specific to the test period can be identified during later analysis.

Record the initial values of any integrating meters, e.g. monitoring fuel or electricity consumption.

Record the barometric pressure.

If necessary, increase the frequency of the output grain sampling to provide at least 12 samples evenly distributed over the test period.

During the test period manually record measurements from any sensors which are not being recorded automatically, e.g. air flow and electrical energy.

At the end of the test period divert the output grain back to the discard store and read the final values on any integrating measuring instruments.

Determine the mass of grain discharged during the test period.

9.1.4 Further test periods

Make any adjustments to the drier settings required for the next test run and repeat the steps described in 9.1.2 and 9.1.3.

9.1.5 Upon completion

Determine the mass of grain remaining in the drier by weighing the grain when emptied from the drier.

9.2 Batch drier procedure

9.2.1 Start up

Fill the drier with damp grain and record the drier holding capacity.

During filling take grain samples as described in 8.2.

Time the filling.

Record the initial values of any integrating meters, e.g. monitoring fuel or electricity consumption.

Record the barometric pressure.

9.2.2 Test period

Set the required drying air temperature using the manufacturer's installed proprietary equipment.

Unless automatically determined, set the cooling period according to the manufacturers' recommendations.

If an automatic method for determining the end of drying is provided, set the target moisture content to correspond to an appropriate moisture.

Start the drier according to any recommended procedures of drier manufacturer.

Thereafter no adjustments shall be permitted unless part of normal drier operation.

If no automatic facility is provided, continue drying for a period corresponding to an appropriate reduction in the average moisture content of the batch.

If an automatic facility is provided, allow it to terminate the drying phase.

During the test period, manually record measurements from any sensors which are not being recorded automatically, e.g. air flow and electrical energy.

At the end of the drying period record the time and the values of any integrating measuring instruments.

Record the length of the cooling period, if any, and the final values of any integrating measuring instruments.

Empty the drier and sample the grain as described in 8.2.

Measure the time taken to complete the emptying.

Determine the mass of grain in the discharged batch.

9.2.3 Further test periods

Make any adjustments to the drier settings required for the next test run and repeat the steps described in 9.2.1 and 9.2.2.

10 Calculation of results

10.1 Serial data

Calculate the mean, standard deviation and standard deviation of the mean of data which were recorded regularly during the test.

10.2 Continuous-flow driers

10.2.1 Mass flow of grain

Calculate the mass flow of dried grain at the drier exit, m'_f, from

$$m'_f = m_f/t$$

10.2.2 Residence time

Calculate the residence time, τ, from the mass flow rate and measured capacity

$$\tau = G/m'_f$$

or from the volumetric capacity and the bulk density of the grain

$$\tau = V\rho_{gf}/m'_f$$

NOTE — The value of τ is not required to great accuracy as it is only used to identify input samples (see 8.2.3).

10.2.3 Input moisture content

Once the residence time, τ, is known, identify the input samples corresponding to the steady-state output and average to give M_i.

10.2.4 Evaporation rate

Calculate the evaporation rate, E', from the mass flow of output grain and the change in grain moisture content from

$$E' = m'_f(M_i - M_f)/(100 - M_i)$$

Calculate the evaporation mass, E, from

$$E = E't$$

Estimate the uncertainty in accordance with B.4.1.

10.2.5 Electrical energy consumption

If the current, voltage and power factor were measured, calculate the electrical power, P_e, from

$$P_e = UI\cos\phi\sqrt{3}$$

where U, I and $\cos\phi$ are the mean values over the test period computed in 9.1.3.

Calculate the electrical energy consumed, W_e, from

$$W_e = P_e t$$

10.2.6 Thermal energy consumption

The method of calculation of thermal power and energy shall depend on the method of heating.

10.2.6.1 Direct heating

Irrespective of the fuel used, calculate the thermal power, P_t, from

$$P_t = FH$$

and the thermal energy, W_t, from

$$W_t = FHt$$

10.2.6.2 Indirect heating

Where the heat exchanger is an integral part of the drier and the objective is to determine the overall efficiency, calculate the thermal power and thermal energy by the formulae of 10.2.6.1.

Where the heat is supplied to the heat exchanger from an external source or where the objective is to determine the efficiency of drying independently from the efficiency of the heat exchanger, calculate the thermal power, P_t, from the heat lost by the heating fluid

$$P_t = X_h(\theta_{hi} - \theta_{hf})c_h$$

and the thermal energy, W_t, from

$$W_t = P_t t$$

If this method is not suitable, the method used shall be described in the report.

10.2.7 Specific thermal energy consumption

The heat used, Q, to evaporate a unit mass of water is given by

$$Q = W_t/E$$

Estimate the uncertainty in accordance with B.4.2.

10.2.8 Specific total energy consumption

The total energy, S, used to evaporate unit mass of water is calculated from the sum of the thermal and electrical energies divided by the evaporation

$$S = (W_e + W_t)/E$$

Estimate the uncertainty in accordance with B.4.3.

10.3 Batch driers

10.3.1 Evaporation

Calculate the evaporation, E, from

$$E = m_f(M_i - M_f)/(100 - M_i)$$

Calculate the mean evaporation rate, E', from

$$E' = E/t_d$$

NOTE — This formula attributes any evaporation during cooling to the drying phase.

10.3.2 Electrical energy consumption

Calculate the overall energy consumed, W_e, from the power in drying and cooling phases from

$$W_e = (P_{ed}t_d + P_{ec}t_c)$$

where

$$t_d + t_c = t$$

10.3.3 Thermal energy consumption

The method of calculation of thermal power and energy shall depend on the method of heating.

10.3.3.1 Direct heating

Calculate the thermal power, P_t, from

$$P_t = FH$$

and the thermal energy, W_t, from

$$W_t = P_t t_d$$

10.3.3.2 Indirect heating

Calculate the thermal power from the formula given in 10.2.6.2.

Calculate the thermal energy, W_t, from

$$W_t = P_t t_d$$

10.3.4 Specific thermal energy consumption

The thermal energy consumption shall be calculated from the formulae given in 10.2.7.

10.3.5 Specific total energy consumption

The specific energy consumption shall be calculated by the formula given in 10.2.8.

10.4 Correction to standard conditions

Correct the results to standard conditions as defined in annex A and in ISO 11520-2.

11 Test report

The test report shall include the following:

— a specification of the drier on which the test was made, including all information recorded in 7.1;

— a description of the installation with details of any aspects which are likely to have affected the performance of the drier;

— a specification of the fuel used during the test stating its type, calorific value and temperature;

— a specification of the input grain as defined in accordance with ISO 11520-2;

— a table of results which summarizes the performance of the drier.

A specimen report is given in annex E. Additionally measured data, graphs and other calculated data may be included in the report.

Annex A
(normative)

Correction to standard conditions

A.1 Limitations

For purposes of comparison and rating it is usually necessary to derive from the observed results an estimate of the likely performance of the drier at specified conditions of grain and air. Because of the complexity of the interactions, the accuracy of correction is difficult to quantify but will reduce as the range, over which the correction is made, increases.

A.2 Air density

Air density shall be corrected so that the corrected fuel consumption can be calculated. Fuel consumption is proportional to mass flow of air which depends on air density at the fan(s). Air density depends amongst other factors, on barometric pressure and on air temperature. These two causes of density change are dealt with separately.

A.2.1 Change in density with barometric pressure

Calculate a correction factor, g_1, from

$$g_1 = p_{bs}/p_{bo}$$

A.2.2 Change in density with air temperature

In driers with a given fan and constant rotor speed, the volumetric airflow will remain substantially constant for a given system of airways and grain resistance, but the mass airflow will change in direct proportion to changes in air density at the fan. Depending upon the position of the fan(s) in the air path the temperature at which to evaluate the air density may be that of ambient, drying or exhaust air.

Calculate a correction factor, g_2, from

$$g_2 = (\theta_o + 273)/(\theta_s + 273)$$

NOTE — Where the fans are pumping air at exhaust conditions, calculation of θ_s is complex and it is unlikely to differ substantially from θ_o. In this case it is reasonable to assume, $g_2 = 1$.

A.2.3 Calculation of corrected density

Calculate the corrected density, ρ_s, using the correction factors, from

$$\rho_s = \rho_o g_1 g_2$$

A.3 Power, energy and fuel consumption

A.3.1 Electrical

Neglecting power consumption of mechanical components other than fans, the change in electrical power will be in the drive to the fan which will vary in proportion to air density. For a continuous-flow drier calculate the corrected electrical power, P_{es}, from

$$P_{es} = P_{eo}(\rho_s/\rho_o)$$

and corrected electrical energy consumption, W_{es}, from

$$W_{es} = P_{es}\, t$$

For a batch drier, calculate the corrected electrical power consumption during the drying phase, P_{esd}, from

$$P_{esd} = P_{eod}(\rho_s/\rho_o)$$

and total electrical energy consumption, W_{es}, from

$$W_{es} = (P_{esd}\,t_{ds} + P_{eoc}\,t_{oc})$$

NOTE — This formula assumes that the cooling process is not affected by the change in drying conditions.

A.3.2 Thermal and fuel

A.3.2.1 Direct heating

Calculate the fuel consumption, F_s, adjusted for the changes in mass flow, temperature at the drier inlet and ambient temperature from

$$F_s = F_o(\rho_s/\rho_o)(\theta_{is} - \theta_{as})/(\theta_{io} - \theta_{ao})$$

Then correct the thermal power consumption, P_{ts}, using

$$P_{ts} = F_s H$$

and correct the thermal energy consumption, W_{ts}, for a continuous-flow drier using

$$W_{ts} = P_{ts}\,t$$

or for a batch drier using

$$W_{ts} = P_{ts}\,t_d$$

A.3.2.2 Indirect heating

Calculate the corrected thermal power consumption, P_{ts}, from

$$P_{ts} = P_{to}(\rho_s/\rho_o)(\theta_{is} - \theta_{as})/(\theta_{io} - \theta_{ao})$$

and the corrected thermal energy, W_{ts}, for a continuous-flow drier from

$$W_{ts} = P_{ts}\,t$$

or for a batch drier from

$$W_{ts} = P_{ts}\,t_d$$

Annex B
(informative)

Estimation of uncertainty of derived measures of performance

B.1 Uncertainty

Uncertainty about the accuracy of a measurement or derived quantity exists because measurements are subject to random and systematic errors. Provided the errors are small and numerous then their combined distribution, can be assumed to be distributed normally about the mean and the uncertainty can be expressed in terms of the characteristics of the normal distribution, i.e. the mean, the standard deviation and the experimental standard deviation of the mean.

B.2 Definitions

B.2.1 Mean value

If a variable Z is measured several times, each measurement being independent of the others, then the mean value, $\overline{Z}$, of n measurements is given by

$$\overline{Z} = \frac{1}{n}\sum_{i=1}^{n} Z_i \qquad \ldots \text{(B.1)}$$

B.2.2 Standard deviation

The dispersion of the observed values of Z about the mean, $\overline{Z}$, is characterized by the experimental standard deviation, s, which is given by

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Z_i - \overline{Z})^2} \qquad \ldots \text{(B.2)}$$

B.2.3 Experimental standard deviation of the mean (SDOM)

The deviation of the observed mean, $\overline{Z}$, from the true mean of the population can be estimated from the dispersion of the measurements about the observed mean value by the experimental standard deviation of the mean (SDOM), $s(\overline{Z})$, which is defined as

$$s(\overline{Z}) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(Z_i - \overline{Z})^2} = s\sqrt{n} \qquad \ldots \text{(B.3)}$$

Provided the precision of the technique and the apparatus used for a measurement are not changed, then the standard deviation will not change significantly no matter how many observations are taken. On the other hand the experimental standard of the mean depends not only on the precision of the technique but also on the number of observations in the sample, i.e. the random error of the mean of n independent measurements is $\sqrt{n}$ times smaller than the random error of individual measurements.

In many cases, repeated measurements of the variable Z are either not available or are not taken because a single reading may be considered adequate. Time is an example; a single clock or stop watch can time steady-state periods of an hour or more to within a few seconds or about 0,1 % (the accuracy is limited by the human operator not by the instrument). Relative to other measurement errors this is likely to be so small at to be negligible.

However, there are other variables, e.g. total fuel use, where the precision of the instrument may not match that of a clock but where a single measurement has to suffice. In such cases, some estimate of the uncertainty is often expressed by a figure for accuracy which may reasonably be taken to be two standard deviations about the mean and since only one reading is taken, i.e. $\sqrt{n} = 1$, then the experimental standard deviation of the mean may also be taken to be one-half of the accuracy value. If this assumption is made it becomes possible to make some estimate of the likely contribution made by errors in measuring individual variables to the error in the derived measures of performance.

B.2.4 Combination of experimental standard deviations of the mean

To assess the random uncertainty of a quantity derived from several measurements it is first necessary to determine an overall SDOM from those of the separate measurements involved.

If the measure of drier performance to be derived is denoted by y then it can be expressed as a certain function of the various independent variables, $x_1, x_2, ..., x_k$:

$$y = f(x_1, x_2, ..., x_k) \quad \text{... (B.4)}$$

If the experimental standard deviations of the means of the variables are $s(\bar{x}_1), s(\bar{x}_2), ..., s(\bar{x}_k)$, then the experimental standard deviation of the mean, $s(\bar{y})$, of the derived performance measure is defined as:

$$s(\bar{y}) = \sqrt{\left(\frac{\partial y}{\partial x_1} s(\bar{x}_1)\right)^2 + \left(\frac{\partial y}{\partial x_2} s(\bar{x}_2)\right)^2 + ... + \left(\frac{\partial y}{\partial x_k} s(\bar{x}_k)\right)^2} \quad \text{... (B.5)}$$

where $\frac{\partial y}{\partial x_1}, \frac{\partial y}{\partial x_2}, ..., \frac{\partial y}{\partial x_k}$, are partial derivatives.

B.2.5 Confidence limits

For a given probability or confidence level, the upper and lower confidence limits are given by $(y + \delta)$ and $(y - \delta)$ respectively where δ is the product of the SDOM and the value of Student's distribution, t, appropriate to the probability or confidence level required and the number of degrees of freedom, and is given by

$$\delta = s(\bar{y})t \quad \text{... (B.6)}$$

B.2.6 Degrees of freedom

The number of degrees of freedom, v, is the number of independent terms which were included in the calculation of the sums of squares. For a straight mean of n observations it is $(n - 1)$. For the SDOM of a quantity, which has been derived from measurements of separate quantities, an "effective number of degrees of freedom", v_{eff}, is given by the following approximate formula

$$\frac{1}{v_{eff}} = \sum_{i=1}^{k} \frac{\left(\frac{\partial y}{\partial x_i} s(\bar{x}_i)\right)^2}{[s(\bar{y})]^2 v_i} \quad \text{... (B.7)}$$

$$= \sum_{i=1}^{k} \left(\frac{\frac{\partial y}{\partial x_i} s(\bar{x}_i)}{s(\bar{y})}\right)^2 \frac{1}{v_i} \quad \text{... (B.8)}$$

$$= \sum_{i=1}^{k} \frac{c_i^2}{v_i} \text{ where } c_i = \left(\frac{\partial y}{\partial x_i} s(\bar{x}_i)\right) / s(\bar{y}) \quad \text{... (B.9)}$$

NOTE — This equation will generally yield a real number which should be rounded down to the next integer value. Also v_{eff} is mainly determined by the component having the largest value of the quantity c_i^2/v_i and minor components have, in many cases, very little influence on v_{eff}. Thus although the estimated standard deviations of single value measurements should be included in the calculation of overall standard deviation for a derived variable, if their relative contribution to the overall value is small, they may be ignored in the calculation of the effective number of degrees of freedom. If their contribution is large, an estimated equivalent number of degrees of freedom is 50 since the assumption that the standard deviation was one-half of the instrument or method accuracy implies a value of t' which is equivalent to 50 or more degrees of freedom at the 95 % level of probability.

B.3 Example of pooling errors in the measurement of a single variable

As an example, consider a drier test in which, the mean, standard deviation and experimental standard deviation of the mean of 12 readings of output moisture content were 16,34, 0,152 and 0,043 9 % m.c.w.b. respectively.

Considering this result on its own, there are 11 degrees of freedom for which the value of t at the 95 % level is 2,228. Therefore, the 95 % confidence limits are

$$2{,}228 \times 0{,}043\,9 = \pm 0{,}098 \text{ \% m.c.w.b.}$$

Since each of the 12 values of moisture was subject to some error during its determination in the laboratory. For the standard oven method used, the result of a properly conducted test should fall within a maximum range of 0,15 % m.c.w.b. (i.e. ± 0,075 %) and therefore equivalent to a standard deviation of the mean equal to 0,037 5.

Pooling this error with the sampling error, the combined standard deviation of the mean from equation (B.5) is

$$\sqrt{(0{,}037\,50)^2 + (0{,}043\,9)^2} = 0{,}057\,7$$

Since the additional error is quite a large proportion of the combined value it should be included in the calculation of v_{eff}, i.e.

$$\frac{1}{v_{eff}} = \left(\frac{0{,}037\,5}{0{,}057\,7}\right)^2 \frac{1}{50} + \left(\frac{0{,}043\,9}{0{,}057\,7}\right)^2 \frac{1}{11} = 0{,}0610 \qquad \ldots \text{(B.10)}$$

Therefore, $v_{eff} = 16$

At 16 degrees of freedom, $t = 2{,}12$, therefore the 95 % confidence limits are ± 0,122 % m.c.

If the number of samples taken had been increased to 24 then the standard deviation of the mean could have reduced to $0{,}152 / \sqrt{24} = 0{,}0310$ and the pooled error from equation (B.5) would be equal to 0,048 67. Then

$$\frac{1}{v_{eff}} = \left(\frac{0{,}037\,5}{0{,}048\,7}\right)^2 \frac{1}{50} + \left(\frac{0{,}0310}{0{,}048\,7}\right)^2 \frac{1}{23} = 0{,}029\,5 \qquad \ldots \text{(B.11)}$$

Therefore, $v_{eff} = 33$

for which $t = 2{,}04$ and thus 95 % limits are ± 0,099, which is about the same as the limits on the original 12 samples only, i.e. in this example, it is necessary to double the number of samples to counterbalance the moisture method error.

B.4 Calculation of the standard deviation of the mean of derived variables

B.4.1 Evaporation

From 10.2.4, and omitting unnecessary subscripts, the mean evaporation for a continuous-flow drier is given by

$$E = m(M_i - M_f)/(100 - M_i) \qquad \ldots \text{(B.12)}$$

There are three variables and the relative standard deviation of the mean can be approximated from equation (B.5) as

$$\frac{s(E)}{E} = \sqrt{\left(\frac{\partial E}{\partial m}\frac{s(m)}{E}\right)^2 + \left[\left(\frac{\partial E}{\partial M_i}\frac{s(M_i)}{E}\right)^2 + \left(\frac{\partial E}{\partial M_f}\frac{s(M_f)}{E}\right)^2\right]} \quad \ldots (B.13)$$

which by differentiation of individual terms on the right-hand side gives

$$\frac{s(E)}{E} = \sqrt{\left(\frac{s(m)}{m}\right)^2 + \left[\left(\frac{(100 - M_f)}{(100 - M_i)(M_i - M_f)}s(M_i)\right)^2 + \left(\frac{-1}{(M_i - M_f)}s(M_f)\right)^2\right]} \quad \ldots (B.14)$$

B.4.2 Specific thermal energy consumption

From 10.2.7, the specific thermal energy consumption for a directly heated continuous-flow drier is given by

$$Q = FHt(100 - M_i)/[m(M_i - M_f)] \quad \ldots (B.15)$$

Then, from equation (B.5), the relative standard deviation of the mean of the specific thermal energy consumption is approximated by

$$\frac{s(Q)}{Q} = \sqrt{\left(\frac{\partial Q}{\partial F}\frac{s(F)}{Q}\right)^2 + \left(\frac{\partial Q}{\partial m}\frac{s(m)}{Q}\right)^2 + \left[\left(\frac{\partial Q}{\partial M_i}\frac{s(M_i)}{Q}\right)^2 + \left(\frac{\partial Q}{\partial M_f}\frac{s(M_f)}{Q}\right)^2\right]} \quad \ldots (B.16)$$

and reduces to:

$$\frac{s(Q)}{Q} = \sqrt{\left(\frac{1}{F}s(F)\right)^2 + \left(\frac{-1}{m}s(m)\right)^2 + \left[\left(\frac{-1}{(M_i - M_f)}s(M_i)\right)^2 + \left(\frac{-1}{(M_i - M_f)}s(M_f)\right)^2\right]} \quad \ldots (B.17)$$

B.4.3 Specific total energy consumption

From 10.2.8, the specific total energy consumption for a directly-heated continuous-flow drier is given by

$$S = \frac{(W_e + W_t)}{E} = \frac{(P_e t + FHt)}{E} = \frac{(P_e t + FHt)(100 - M_i)}{m(M_i - M_f)} \quad \ldots (B.18)$$

By similar arguments it can be shown that the experimental standard deviation of the mean is given by

$$\frac{s(S)}{S} = \sqrt{\left(\frac{1}{F}s(F)\right)^2 + \left(\frac{1}{P_e}s(P_e)\right)^2 + \left(\frac{-1}{m}s(m)\right)^2 + \left[\left(\frac{-1}{(M_i - M_f)}s(M_i)\right)^2 + \left(\frac{-1}{(M_i - M_f)}s(M_f)\right)^2\right]} \quad \ldots (B.19)$$

B.4.4 Example of pooling errors in the measurement of several variables

Assume that fuel is measured to within ± 2 %, then $s(F)/F = 1\ \% = 0{,}01$; power is measured to within ± 1 % then $s(P_e)/P_e = 0{,}5\ \% = 0{,}005$; mass is measured to within ± 0,1 % then $s(m)/m = 0{,}05\ \% = 0{,}000\ 5$, then the experimental standard deviation of the mean of the specific total energy consumption is given from equation (B.19) as

$$\frac{s(S)}{S} = \sqrt{(0{,}01)^2 + (0{,}005)^2 + (0{,}000\ 5)^2 + (\text{moisture terms})^2}$$

$$= \sqrt{(0{,}011\ 19)^2 + \left[\left(\frac{1}{(M_i - M_f)}\, s(M_i)\right)^2 + \left(\frac{1}{(M_i - M_f)}\, s(M_f)\right)^2\right]} \qquad \ldots \text{(B.20)}$$

Let $M_i - M_f = 5{,}0$

Assume that the range in $s(M_i)$ and $s(M_f)$ may be from ± 0,04 % to ± 0,2 %. Therefore,

$$s(M)/(M_i - M_f)^2$$

may range from

$$(0{,}04/5)^2 = (0{,}008)^2 \quad \text{to} \quad (0{,}2/5)^2 = (0{,}04)^2$$

In the worst case,

$$\frac{s(S)}{S} = \sqrt{(0{,}011\ 19)^2 + (0{,}04)^2 + (0{,}04)^2} = 0{,}057\ 7$$

and from equation (B.7)

$$\frac{1}{\nu_{\text{eff}}} = \left(\frac{0{,}011\ 19}{0{,}057\ 7}\right)^2 \frac{1}{50} + \left(\frac{0{,}040\ 0}{0{,}057\ 7}\right)^2 \frac{1}{11} + \left(\frac{0{,}040\ 0}{0{,}057\ 7}\right)^2 \frac{1}{11} = 0{,}088\ 3$$

Therefore, with an effective number of degrees of freedom, $\nu_{\text{eff}} = 11$ giving a value of $t = 2{,}201$ at a probability of 95 %, the uncertainty in the estimation of the specific total energy consumption is:

$$\pm\ 0{,}057\ 7 \times 2{,}201 = \pm\ 0{,}127$$

$$= \pm\ 12{,}7\ \%$$

Similarly, in the best case,

$$\frac{s(S)}{S} = \sqrt{(0{,}011\ 19)^2 + (0{,}008)^2 + (0{,}008)^2} = 0{,}015\ 9$$

$$\frac{1}{\nu_{\text{eff}}} = \left(\frac{0{,}011\ 19}{0{,}015\ 9}\right)^2 \frac{1}{50} + \left(\frac{0{,}008\ 0}{0{,}015\ 9}\right)^2 \frac{1}{11} + \left(\frac{0{,}008\ 0}{0{,}015\ 9}\right)^2 \frac{1}{11} = 0{,}055\ 9$$

$\nu_{\text{eff}} = 17$ for which $t = 2{,}11$ at the 95 % level of probability, and therefore the uncertainty in the estimation of the specific total energy consumption reduces to

$$\pm\ 0{,}015\ 9 \times 2{,}11 = \pm\ 0{,}033\ 6$$

$$= \pm\ 3{,}36\ \%$$

Table B.1 below shows the effect on the uncertainty of varying the moisture removal $(M_i - M_f)$. The 95 % confidence limits increase non-linearly as moisture removal is reduced and, in the worst case, become unacceptably high at values of $(M_i - M_f)$ less than 5 %.

Table B.1 — Effect of moisture removal on the uncertainty of the estimate of specific total energy consumption

Moisture removal, $(M_i - M_f)$ % m.c.w.b	95 % Confidence limits ± %	
	Best case	Worst case
10	2,05	7,45
5	3,36	12,7
4	3,89	15,8
2	7,45	31,2

Annex C
(informative)

Checklist

C.1 First visit on site

C.1.1 Facilities

Check the following facilities:

— grain dampening facilities (water supply, clean surface or hopper for grain mixing, bucket loader);

— weighing facilities (weighbridge of portable weighing facilities, calibration facilities);

— electricity supply (one- or three-phase supply, tension and current capacity, connection points for instruments for power measurements, connection point for measurement on drier alone);

— site for housing of instruments (distance from drier, length of sensor cables, risk of electrical interference);

— storage (trailers for transport, distance to, and capacity of, storage facilities for both wet and dry grain, separate storage for grain subjected to thermal damage);

— grain handling system (means to divert grain flow for weighing during test, capacity of augers or conveyors for feeding and discharging grain, absence of grain leaks, access point for grain sampling);

— sensors (number of sensors, wire lengths, suitable positions for temperature, humidity and pressure sensors);

— heating system (fuel type and system of supply, location of measuring devices, direct or indirect heating of dry air).

C.1.2 Drier specification and capacity

Check that the drier is in good working order. Make a record of the drier specification (see annex E).

C.1.3 Measurement of fuel consumption

Check that the measuring system is dependent on the energy source for the air heater.

C.1.3.1 Liquid fuels

C.1.3.1.1 Continuous-flow methods

If the fuel supply system is equipped with a "return" line, the sensor should be installed after the return line so as to measure only the fuel actually consumed by the heater. A less accurate method is to install two sensors, one in the return, and one in the flow, line. The consumption is then calculated by subtraction. Make sure the sensor will not restrict the fuel supply by causing a large pressure decrease.

C.1.3.1.2 Batch methods

The mass of fuel consumed may be determined by weighing, or measuring the density and volume of, a supply before and after the test. Preferably a small temporary fuel container with well defined volume/area should be used.

C.1.3.2 Gaseous fuels

The consumed mass of gaseous fuels can be determined by measuring volume and density at the start and end of the test. All measurements must be corrected for derivations in temperature and pressure.

C.1.3.3 Solid fuels

Weighing the fuel consumed is the most suitable method.

C.2 Off-site preparations

C.2.1 Grain quantity

Calculate the quantity of grain with the aid of the equation given in 7.2, taking into account drying conditions and the number of tests. For continuous-flow driers also consider output rate and duration of tests.

Check that the capacity of the grain handling system (mixing-dampening, augers-conveyors, storage-transport) is adequate.

C.2.2 Grain quality

Record the grain specification according to E.4.

C.2.3 Sensors and measuring system

Decide which measuring system is to be used and check that sensors/devices are adequate in number and accuracy for the following measurements:

— temperature of ingoing and outgoing grain;
— air temperatures (drying, cooling, exhaust);
— air humidity;
— barometric pressure;
— fuel consumption;
— electrical energy consumption;
— moisture content (rapid meter);
— grain mass;
— static pressure;
— humidity of outgoing air;
— airflow.

NOTE — When the drier is operating, sensors will experience considerable buffeting. In open areas of plenum chambers and ducts it is normally necessary to install tightly stretched wires to which the sensors may be fixed.

C.2.4 Grain sampling

Consider where moisture content and germination tests will be performed. Consider whether samples will be bulked, stored or dried.

Check that sample dividing equipment and the necessary containers are available. Containers will be needed for:

— grain temperature samples (insulated containers);
— moisture content samples;
— other samples as described in ISO 11520-2.

C.2.5 Uncertainties

Check the uncertainties (see annex B).

Annex D
(informative)

Air flow measurement and calculations

D.1 Measurement of air flow

It is not obligatory to make direct measurements of the air flow into or out of the drier. However, the evaporative capacity of a drier is strongly dependent on the flow of heated air through the grain and it is important to determine this flow accurately if a computer simulation of the drier test is to be done. Some direct methods of air flow measurement may obstruct, and thus reduce, the air flow, but where there is a choice of methods it is considered more important to measure air flow accurately than to avoid obstruction, as performance under normal air flows can later be corrected using methods in D.3. Because of the difficulty of measuring air flows in grain driers, both direct and indirect methods should be used.

D.1.1 Direct measurement

The method used should follow ISO 3966 or ISO 7194. Where this is not possible because of the physical characteristics of the air paths the test report will contain notes to this effect. Depending on the design of the drier, the air to be heated may enter the drier together with any air to be used for cooling or the streams may be separate. If the streams are separate, both will be measured. If combined, the measured flow is ascribed to the drying and cooling sections by a method given in D.2 which is based on the measured static pressure drop across the drying and cooling sections. If direct measurements of air flow are to be made using pitot static tubes, holes in duct walls may be required for insertion of the tubes.

If standard inlet cones conforming to ISO 3966 are used to measure the total air flow directly, measurements of static pressure drop across the grain bed are made with and without the device in position to determine the reduction in air flow which it causes.

NOTES

1 Corrections to the air flow can be made using the method in D.3.

2 Where no duct of regular shape is available, or the flow is fluctuating or swirling or with a very non-uniform velocity profile, point measurements may still be used but with significantly reduced accuracy. Errors in these cases are likely to be so large that secondary methods of calculating the air flow are preferred.

3 Air supplied to the burner for combustion of fuel may also pass through the grain in direct fired driers. If this air is not also passing through another air flow measuring device, it is either measured, or calculated from the fuel composition by stoichiometric methods.

D.1.2 Indirect measurement

Heated air mass flow rate, q_m, is calculated from

$$q_m = \eta F_o H / [c_{pa}(\theta_d - \theta_a)] \quad \ldots (D.1)$$

This formula includes the efficiency with which the heater converts the fuel calorific value into heating of the air. It is not within the scope of this International Standard to calculate the thermal efficiency of the heater, but if a value of η is known, the accuracy of the above formula will be improved. Otherwise a value of $\eta = 1$ shall be assumed. In the case of a heat exchanger supplied with heating fluid from an external source calculate the thermal power from the formula given in 10.2.6.2.

If an accurate curve of fan static pressure versus air flow is available, measurements of static pressure rise across the fan, made in accordance with 7.3.4, may be used to determine the flow through it. Adjustment should be made for any difference in density between the air used to derive the curve and the test air conditions.

D.2 Derivation of formulae for apportioning air volume flow between drying and cooling beds of a drier

The relationship between the air superficial velocity, v, through a packed bed of grain and the pressure drop, p, across the bed can be approximated by[1)]

$$v = (p/id)^j \quad \text{... (D.2)}$$

or

$$v = k(p/d)^j \quad \text{... (D.3)}$$

where $k = (1/i)^j$

Now, the drying air volume flow rate, q_{vd}, can be expressed as

$$q_{vd} = vf_d$$

Substituting for v from equation (D.3)

$$q_{vd} = f_d k \left(\frac{p_d}{d_d}\right)^j \quad \text{... (D.4)}$$

Similarly for the cooling flow

$$q_{vc} = f_c k \left(\frac{p_c}{d_c}\right)^j \quad \text{... (D.5)}$$

Dividing equation (D.4) by equation (D.5) gives

$$\frac{q_{vd}}{q_{vc}} = \left(\frac{f_d}{f_c}\right)\left(\frac{p_d d_c}{p_c d_d}\right)^j \quad \text{... (D.6)}$$

hence

$$q_{vd} = q_{vc}\left(\frac{f_d}{f_c}\right)\left(\frac{p_d d_c}{p_c d_d}\right)^j \quad \text{... (D.7)}$$

The drying air volume flow rate, q_{vd}, is also given by

$$q_{vd} = q_{vn} - q_{vc} \quad \text{... (D.8)}$$

hence, by equating and rearranging equations (D.7) and (D.8)

$$q_{vc} = \frac{q_{vn}}{\left[1 + \left(\frac{f_d}{f_c}\right)\left(\frac{p_d d_c}{p_c d_d}\right)^j\right]} \quad \text{... (D.9)}$$

Similarly

$$q_{vd} = \frac{q_{vn}}{\left[1 + \left(\frac{f_c}{f_d}\right)\left(\frac{p_c d_d}{p_d d_c}\right)^j\right]} \quad \text{... (D.10)}$$

1) Matthies and Petersen, Transactions of the American Society of Agricultural Engineers, 1974, 17 (6), pp. 1144-1149.

Thus if in the total flow, the pressure drops across each bed and the relative depth of each bed are known, the total air flow can be apportioned between the drying and cooling beds.

This derivation ignores change of air velocity with air density when the temperatures in the two grain zones differ, but this is reasonable as other factors are also ignored, for example

— pressure drops other than those due to grain beds;

— the effect of non-linear flow;

— the fact that equations (D.2) and (D.3) are valid for near-ambient temperatures.

Values of j for specific crops can be found in scientific literature. For wheat, barley and oats, a value of 0,75 will give reasonable results.

Note that for a mixed-flow drier the area of the exposed grain face at the point of air entry is proportional to the number of complete (whole plus half) inlet ducts. Therefore, to evaluate f_c/f_d only the ratio of the number of complete ducts needs to be calculated.

D.3 Effect of the standard inlet cone on air flow

If the static pressure drop across the grain bed is measured with and without the flow restriction caused by the inlet cone, the restricted air velocity, v_u, can be calculated from

$$v_u = v_r(p_u/p_r)^j \quad \ldots \text{(D.11)}$$

where the subscripts are r and u refer to restricted and unrestricted cases respectively. The mass air flows are calculated in the same way, since it can be assumed that air density changes between the restricted and unrestricted cases are negligible.

D.4 Humidity of exhaust air

The humidity of the exhaust air may be useful to determine the degree of exhaust saturation and to cross-check the air flow using the measured moisture loss from the grain. If the exhaust air passes through a fan the overall humidity may be measured by a single sensor located downstream of the fan which acts as an air mixer. If no fan is present, the sensor should be located as far downstream as possible to allow air mixing to occur. Care should be taken that no air enters the exhaust stream and that no condensation of moisture occurs between the drier and the sensor. Care should be taken to protect the sensor from dust and fine particles in the atmosphere near the drier, especially in the exhaust air. The exhaust air may be close to, or at, saturation, and sensors may need to be pre-heated before insertion to avoid condensation forming on them. Sensors may be required to operate in air conditions close to saturation. If the sensor requires a restricted or controlled air flow, any system used for extracting air from the exhaust stream shall not allow the extracted air to lose moisture by condensation, or allow the ingress of other air.

Annex E
(informative)

Example format for test report

E.1 Specification of drier

E.1.1 Make: .....

E.1.2 Model and year: .....

E.1.3 Type:

Continuous ☐ Batch ☐ Grain recirculation ☐ Air recirculation ☐ Other ☐

E.1.4 Serial number: .....

E.1.5 Manufacturer: .....

E.1.6 Grain chambers

Drier:

— type, shape: .....
— length (diameter): ..... mm
— height: ..... mm
— width (grain column thickness): ..... mm
— any obstructions (ducts, etc.): .....

Cooler:

— type, shape: .....
— length (diameter): ..... mm
— height: ..... mm
— width (grain column thickness): ..... mm
— any obstructions (ducts, etc.): .....

E.1.7 Capacity

Volumetric grain holding capacity (wet volume in case of batch drier): ..... m^3

E.1.8 Grain discharge

Metering device:

— type: .....
— number of elements: .....
— control drive arrangement: .....